SANTA FE RESEARCH CORPORATION

AIR QUALITY BENEFIT ANALYSIS FOR LOS ANGELES AND SAN FRANCISCO BASED ON HOUSING VALUES AND VISIBILITY

EXECUTIVE SUMMARY

by

John Trijonis, Santa Fe Research Corporation
Mark Thayer, San Diego State University
James Murdoch, Northeast Louisiana University
Ronda Hageman, San Diego State University

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Research Division
California Air Resources Board
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Sacramento, California 95812

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ABSTRACT

Benefits of improved air quality are estimated by examining the public's willingness to pay for visibility as revealed in home sale prices. The investigation is conducted for the 1978-79 period in two study areas, Los Angeles (four counties) and San Francisco (five counties). The analysis uses an extremely large, finely resolved data set for visibility levels, home sale prices, and house/community/location/socio-economic characteristics. The data are gathered from 39 airport weather stations (visibility), the Market Data Cooperative (home sale prices and house specific characteristics), as well as the Census and other data sources (other characteristics).

The economic analysis follows the hedonic price method. First, home sale price is related statistically to visibility and the house/community/location/socio-economic characteristics. The results (including the hedonic price for visibility) are statistically significant, have the expected sign, and are stable with respect to various sample sizes, visibility indices, model formulations, and functional forms. Next, the "hedonic price" for visibility is related to visibility levels and income levels in order to determine the economic (inverse) demand curve. This demand curve in turn yields estimates of benefits. It is found that, depending on assumed functional form, a 10% improvement in visibility would produce benefits of 250-617 million dollars per year in Los Angeles and 190-220 million dollars per year in San Francisco.

A demonstration is made of how to apply the results through an illustrative example -- benefits of controlling diesel particle emissions in Los Angeles. It is estimated that the elemental carbon component of diesel particle exhaust contributed 12% of Los Angeles' visibility reduction in 1980, and that diesel emissions will grow by a factor of 2.3 from 1980 to 1992 under a "no-control" scenario. It is found that 50% control of diesel elemental carbon emissions would yield benefits of one to five billion dollars over the 1980-1992 period. The benefits are substantially reduced by postponing and phasing-in controls.

EXECUTIVE SUMMARY

This study places an economic value on improved air quality by investigating the public's willingness to pay for visibility as revealed in housing market data. Specifically, we examine the relationship between housing values and visibility, discounting for the effects of other collinear variables (house/community/location/socio-economic characteristics). This relationship serves as the basis for determining an economic (inverse) demand curve for visibility which in turn allows estimation of the benefits associated with improved air quality.

In this project, emphasis is placed on what individuals perceive, as visibility is the object of the valuation exercise. The presumption is that all components of air quality valued by people are included in perceived visibility, and no attempt is made to separately value the independent components of air quality.

The analysis uses an extremely large, finely resolved data set for visibility levels, housing values, and house/community/location/socio-economic parameters. The study is conducted for the 1978-79 time period in two study areas, Los Angeles (four counties) and San Francisco (five counties). The report also demonstrates how the results can be applied through an illustrative example -- the benefits of controlling diesel particle emissions in Los Angeles.

The remainder of the Executive Summary is organized according to the three main chapters of the report: Description of the Visibility Data (Chapter 2), Estimation of Benefits from Visibility Improvement (Chapter 3), and Illustrative Application: Diesel Particulate Control in Los Angeles (Chapter 4).

CHAPTER 2: DESCRIPTION OF THE VISIBILITY DATA

Weather Station Visibility Data: Compilation and Analysis

One of the inputs required for the statistical analysis is information on visibility levels throughout the two study areas. The visibility data used herein consist of visual range observations made at airports and other weather stations. Specifically, data are compiled for three observations per day at twenty-one Los Angeles stations and eighteen San Francisco stations during each day of 1973-74 and 1978-79.

For the purposes of this study, the airport visibility data generally appear to be of good quality. The quality of the data was assured by conducting surveys at the weather stations and by scrutinizing the statistical distributions of the data. Because of the nature of reporting practices at airports, special techniques documented in the literature have been applied in determining cumulative frequency distributions and in calculating visibility statistics.

Visibility (Extinction) Indices

Maps of visibility in the Los Angeles area reveal that the lowest median visual range in the basin, about 7 miles, occurs in the San Gabriel and Pomona Valleys. Median visual range improves toward the west and east, to about 11 miles along the western coast and to over 25 miles in the San Gorgonio pass. Visibility is significantly higher in San Francisco than in Los Angeles. There are two notable hot spots in the San Francisco area where visual range is about 13 miles -- the San Francisco-Oakland urban core and the Southern Bay area around San Jose. However, the San Francisco area otherwise demonstrates median visibility of about 15 to 25 miles. Comparing maps for the two time periods indicates that a slight but not uniform improvement in visibility occurred in both study areas from 1973-74 to 1978-79.

For use in the economic regression studies, the visual range data are converted to atmospheric extinction data. The atmospheric extinction coefficient represents the fraction of light that is lost per unit distance as a light beam traverses the atmosphere. In a uniform atmosphere, a simple reciprocal formula relates extinction (B) to visual range (V): $B = k/V$, where "k" is a constant that depends on the observer detection threshold.

Extinction is generally considered preferable to visual range as a scientific measure of visibility. In addition, extinction seems preferable in this study for two practical reasons. First, economic regressions using extinction agree with the known principle that humans perceive a unit change in visual range much more at low visibilities (e.g. from 1 to 2 miles) than at high visibilities (e.g. from 100 to 101 miles). Second, airport data are known to be of relatively higher quality at lower visibilities than at higher visibilities; using extinction rather than visual range emphasizes the variations in the higher quality part of the data rather than the variations in the lower quality part of the data.

In each study area and each time period, three indices of extinction are compiled for use in the economic studies. These indices are median annual extinction for all hours, median annual extinction for hours excluding precipitation or fog, and median annual extinction with sea haze contribution subtracted out. It turns out that the first two indices are so highly intercorrelated that they yield identical results. The third index is not that highly correlated with the other two, but it nevertheless again leads to similar conclusions in the economic analysis.

CHAPTER 3: ESTIMATION OF BENEFITS FROM VISIBILITY IMPROVEMENT

Methodological Review

The economic analysis used herein follows the Freeman-Rosen approach for identifying demand curves of commodities not normally traded in markets. The essential element of the Freeman-Rosen approach, as applied to housing data, is the "hedonic" price function which relates the price of a home to its characteristics (structural, locational, neighborhood, and environmental aspects). This function allows determination of the implicit or hedonic price of each characteristic (i.e. visual air quality), which can be interpreted as the individual's marginal willingness to pay for that characteristic.

The individual's marginal willingness to pay for air quality depends upon other housing characteristics and the individual's characteristics, especially income. The second stage of the hedonic procedure is to estimate the relationship between marginal willingness to pay and these other characteristics. This latter relationship can be interpreted as the (inverse) demand curve for air quality, since it connects price to quantity and other shift variables. The benefits of a specific air quality change can be determined by integrating the inverse demand curve over the proposed improvement.

Until recently, the basic Freeman-Rosen framework has been widely accepted as a means of estimating the benefits of environmental improvements. However, the procedure has lately been criticized as being inappropriate under certain conditions. The criticisms have focused on two issues: (1) the functional form of the hedonic equation in the first stage, and (2) the identification of the (inverse) demand curve in the second stage.

With respect to the first issue, there are no clues as to the correct shape of the hedonic function. Therefore, sensitivity analysis is employed in this study to determine a range of benefit estimates. With respect to the second issue, various authors have questioned whether sufficient information exists for estimating the demand curve. Two possible solutions are utilized here: (1) combining data from multiple markets to yield information on how individuals respond to different price sets, and (2) using data from a single market but imposing further restrictions on possible functional forms.

Data Specifics

Implementation of the hedonic approach requires two data sets. The first data set includes the sale prices of numerous homes and their attributes (structure, neighborhood, community, and environment). The data on sale price and house structure were obtained from the Market Data Cooperative for the 1978-79 time period. Structural variables pertain to both quantity (square footage, number of bathrooms, etc.) and quality (pool, fireplaces, view, etc.). A very large number of observations were used to provide robust statistical estimation properties. Neighborhood refers to the surrounding census tract and includes the variables -- population, age, ethnic composition, distance to work, and distance to the beach. Community (city level) variables encompass density, school quality, crime rate, and others. The final variable included in the hedonic modeling is atmospheric light extinction, discussed in Chapter 2. The neighborhood, community, and light extinction data were matched with the household data using Thomas Brothers maps (4 x 4 km grid squares).

Once hedonic prices (marginal willingness to pay) for light extinction improvements have been determined from the first data set, the second step of the approach is to determine the shape of the inverse demand curve. This is done by relating the hedonic prices to light extinction and income. The data base for this second step is compiled at the community level.

Empirical Results: Hedonic Housing Value Equations

Given the data as described above, the hedonic technique consists of a two-stage estimation procedure. The initial task is to determine the relationship between home price and its characteristics. This procedure allows one to focus on the significance of light extinction while separating out the influence of other extraneous variables.

Benchmark hedonic housing value equations are estimated for both the Los Angeles and San Francisco areas. A number of aspects of the benchmark results are worth noting. First, the non-linear specifications are significant improvements over linear forms. Second, a large proportion of the variation in home sale price is explained by the independent variable set. Third, the independent variables generally possess the expected relationship to home sale price and are significantly different from zero at the one percent level.

However, the most important result from the perspective of this study is that the extinction variable is significantly different from zero and possesses the expected relationship to home sale price. Evidently, individuals are acting upon extinction information when making locational choices, with the action translated into a measurable hedonic gradient. This result is essentially invariant with respect to various sample sizes, extinction measures, model formulations, and functional forms.

The value of a hypothetical ten percent change in extinction ranges from approximately .7 - 2.1 percent of home price in the Los Angeles area and from 1.4 - 2.5 percent of home price in the San Francisco area. The specific value within an air basin is primarily dependent upon functional form.

Empirical Results: Inverse Demand Equations

The second stage of the hedonic price technique is to determine the inverse demand curve for light extinction. As discussed above, this step relates the individual marginal willingness to pay (hedonic price) to extinction level and income.

The inverse demand curves for the Los Angeles and San Francisco areas possess a number of noteworthy aspects. First, a large proportion of the variation in marginal willingness to pay is explained by the variables quantity (extinction) and income. Second, linear forms outperform non-linear forms. Third, the independent variables are generally significant at the one percent level. Finally, an interesting phenomenon occurs in the Los Angeles area only, where the inverse demand curves suggest that residents may be willing to pay even more for each unit decrease in extinction as air quality improves. This seemingly demonstrates what economists call "non-convex" preference patterns. However, since the hedonic housing equations are non-linear, no interpretation can really be attached to the inverse demand curves regarding convexity of preferences.

The magnitude of air quality benefits can be illustrated by calculating the annual basinwide benefits associated with a hypothetical ten percent improvement in visibility. These benefit figures are obtained by integrating the inverse demand curves over the proposed visibility change and summing over all households. The benefit estimates are dependent upon the functional form of the hedonic price equation. This is especially true for the Los Angeles area where benefits range from 250 to 617 million dollars per year (depending on functional form) for a ten percent change in visibility. The San Francisco results are not as dependent upon functional form, ranging from 190 to 220 million dollars per year for a similar ten percent improvement.

The range of benefit estimates discussed above utilize the classic hedonic approach as developed by Freeman and Rosen with an added functional form restriction. An alternative approach is to pool the data across markets and estimate one multi-market inverse demand curve. This approach requires the assumption that individual preferences be identical across the markets. The use of multiple markets adjusts the estimates in the manner anticipated. For instance, adding San Francisco households into an analysis of the Los Angeles area increases the benefit estimates since San Francisco home prices seem to show more sensitivity to visibility degradation.

CHAPTER 4: ILLUSTRATIVE APPLICATION: DIESEL PARTICULATE CONTROL IN LOS ANGELES

Relationship Between Diesel Particle Emissions and Visibility

The benefit analysis for a specific emission control strategy separates into two basic parts. First, one must determine the degree of visibility improvement associated with the control strategy (this subsection). Second, the benefits produced by the visibility improvement are estimated using the economic inverse demand curve (the following subsection).

The current visibility impact from diesel road vehicles (essentially heavy-duty trucks) is estimated using two models, an emission budget model and a lead tracer model. These two models indicate that heavy-duty diesels presently contribute about 20 percent of light extinction in the Los Angeles basin. This 20 percent is composed of 12 percent from the elemental carbon component of particle exhaust, 1 percent from other primary particle emissions, 4 percent from secondary products of NO_x emissions, and 3 percent from secondary aerosols due to SO_2 emissions. Because this example is concerned with directly-emitted particles (i.e. particulate emission standards), and because nearly all of the visibility effects from primary diesel particles are due to elemental carbon, the application study is restricted to only the contribution from elemental carbon particle emissions.

The lead tracer model calibrated against the average of the two models considered provides a detailed spatial distribution for the diesel visibility effects. In absolute terms, the greatest extinction contributions from current diesel elemental carbon emissions occur in a triangle from the San Fernando Valley to Long Beach in the west out to San Bernardino in the east.

The effect of future diesel emissions on extinction can be estimated by proportioning the current spatial distribution of diesel impacts according to emission changes. This can be done for emission growth increases, emission control decreases, or combinations of both.

For the purpose of control strategy analysis, elemental carbon emissions from diesel road vehicles are projected for a "no control" scenario covering 1980 to 1992. Without control, diesel emissions are forecasted to increase by a factor of 2.3 from 1980 to 1992. This rapid increase in emissions results from two factors, overall growth in highway traffic and partial conversion of gasoline cars and trucks to diesel power. It is noteworthy that, even in 1992, heavy-duty vehicles would still account for nearly 90 percent of total diesel fleet emissions. The benefit analysis considers various degrees of control applied to forecasted diesel emissions.

Benefit Estimation

A variety of control scenarios are examined for diesel particulate emissions, with calculated benefits representing the change from "no control" to the specified level of control. Benefits are computed over the 1980-1992 time period, at the community level, for various discount rates, with results expressed in terms of constant 1980 dollars.

Following the traditional Freeman-Rosen approach, the Los Angeles inverse demand equations are mathematically integrated over the visibility improvement to determine individual household benefits. Aggregate benefits then come from summation over the relevant population. The calculations are illustrated herein through a specific example. Results are presented for four alternative functional forms and two alternative discount rates.

In the first scenario, diesel emissions are assumed to be fixed over time, and a constant 50 percent particulate control level is imposed over the entire 1980-1992 time period. All subsequent scenarios are more realistic in that uncontrolled diesel emissions are allowed to grow over time. Scenario II considers 50 percent control of forecasted emissions starting in 1980. Fifty percent is approximately the degree of control being considered for state and national emission standards. Scenario III is similar to Scenario II, except that 80 percent control is assumed. Scenario IV considers the effect of phasing in controls by assuming that no emission reduction is imposed until 1985, and that control is phased in linearly up to 50 percent in 1992.

The net benefits, averaged over the four functional forms and the two discount rates, are as follows: $2.2 billion for Scenario I, $2.7 billion for Scenario II, $4.5 billion for Scenario III, and $.98 billion for Scenario IV. Scrutiny of the results leads to several general conclusions. First, the benefits grow disproportionately as control levels increase, but this effect is relatively minor for marginal changes in extinction. Second, the larger the control effect, the larger the corresponding benefits. The third conclusion, that the benefits of stringent control on basin-wide extinction should be extremely large, arises from a combination of the first two factors. This occurs because (1) the larger the control the larger the benefits, and (2) as pristine air quality is approached, benefits grow at an increasing rate due to the shape of the demand curve. The fourth feature is the substantial loss in benefits from postponing and phasing controls (i.e. Scenario IV).